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KOHOUTEK PHOTOMETRIC PHOTOGRAPHY EXPERIMENT (S233) FINAL REPORT

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16. ABSTRACT

This report presents the final results of the Skylab 4 experiment S233, Kohoutek Photometric Photography Experiment, which undertook a series of visible light photographs suitable for photometry and for a photographic history of Comet Kohoutek. The report explains the experiment concept, the data reduction method, and the results obtained.

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KOHOUTEK PHOTOMETRIC PHOTOGRAPHY EXPERIMENT (S233) FINAL REPORT

I. EXPERIMENT CONCEPT AND EXECUTION

The Kohoutek Photometric Photography Experiment, S233, assigned to the Skylab 4 mission, undertook a series of visible light photographs suitable for photometry and for a photographic history of the comet. This conceptually simple experiment evolved from a July 3, 1973, NASA Headquarters request to the Marshall Space Flight Center and the Johnson Space Center for an assessment of a program of Comet Kohoutek observations utilizing existing Skylab sensors or other instruments that could be available in time for Skylab 4. One possible observation identified in response to this request proposed the use of existing cameras to take comet photographs through the spacecraft windows. These observations were included in a set of new and amended experiments for Skylab 4 accepted by NASA on October 23, 1973. References 1 and 2 provide a summary of the various observations of the comet from Skylab.

The camera available for the S233 photography was a 35-mm Nikon camera with a 55-mm focal length, adjustable focus, f/1.2 lens [3]. The field of view was 36 by 24 degrees, which yields a 1.04 degree per mm image on the photographic film. This film format seemed appropriate, inasmuch as a long comet tail was expected. Also, camera pointing was to be accomplished manually by the Skylab crew, and an ample field of view was desirable to accommodate pointing uncertainties.

The film selected was Kodak Plus-X Aerial 3401 on a thin base. The choice was made on the basis of availability, resolution, speed, radiation effects, and other pertinent factors. Four cassettes of 60 exposures per cassette were provided for the experiment.

The standard observation sequence adopted is shown in Table 1. The exposures focused at 15 ft produced a slightly out of focus image of the comet and surrounding star field. This was done to insure that stellar images to be used for photometric references would not have saturated cores which could have precluded accurate photometry. Based on premission tests, it was expected that for a 60-sec exposure focused at 15 ft, the faintest star recorded would typically be 6-7 magnitude. For a 120-sec exposure focused at infinity, the faintest star would typically be 9-10 magnitude. This sensitivity was considered adequate for the predicted magnitude of the comet. These limiting magnitude values were obtained on the flight film.

TABLE 1. EXPOSURE SEQUENCES

STANDARD OBSERVATION SEQUENCE	
60-sec exposure	15-ft focus
120-sec exposure	infinity focus
60-sec exposure	15-ft focus
CALIBRATION SEQUENCE	
Unexposed	
10-sec exposure	15-ft focus
30-sec exposure	15-ft focus
60-sec exposure	15-ft focus
120-sec exposure	15-ft focus
120-sec exposure	infinity focus

A calibration sequence of exposures, as shown in Table 1, was performed at least once on each roll of film to allow an observational check of the density-versus-log-exposure curve for the film. Preflight and postflight standard density step-wedge exposures were added to the film in each cassette. The density-versus-log-exposure curve used in data analysis came primarily from the step-wedge images which were added postflight.

The operation plan for the experiment called for a standard observation sequence every 12 hr when possible during the Skylab 4 mission [4]. This had the objective of producing a uniform set of low resolution comet photographs. If obtained, such a set could serve as a reference record of the gross changes in the comet appearance and magnitude.

After the successful completion of the Skylab 4 mission, the S233 films were processed in the photographic laboratories at the Johnson Space Center. The useful photographs were then identified by the investigators at the Marshall Space Flight Center. Density values for these photographs were subsequently measured with a microdensitometer at the Johnson Space Center. These density data are the basic information from which the results discussed later are derived.

Of course, many details must be handled with care in the course of data processing and analysis. These detailed topics, such as background corrections and vignetting, are reviewed in the later sections of this report. However, the broad description of the experiment concept and execution given in this section is sufficient to introduce a discussion of the results obtained. These are discussed in the next sections. Readers who are interested specifically in how the results were derived can examine the later sections.

II. PHOTOGRAPH STATISTICS

Table 2 characterizes each photograph from the four film cassettes returned from Skylab 4 for the S233 experiment. Thirty-five standard or

TABLE 2. PHOTOGRAPH CHARACTERISTICS

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-186-						
6728	327	11/23/73			7 12	Exposure time and focus setting are not known.
6729					7 12	
6730					7 12	
6731	328	11/24/73			7 12	
6732					7 12	
6733					7 12	
6734					7 12	
6735	329	11/25/73	60	15	1 6	
6736			120	inf	1 7	
6737			60	15	1 6 7	
6738	330	11/26/73	60	15	1 6	
6739			120	inf	1 2 4 5	
6740			60	15	1 5 10	
6741	331	11/27/73	60	15	12	
6742			120	inf	1 2 4 5	
6743			60	15	12	
6744	331	11/27/73	60	15	11	
6745			120	inf	7 12	
6746			60	15	12	
6747	332	11/28/73	60	15	11	
6748			120	inf	6 9	
6749			60	15	6 9	
6750					11 12	
6751	332	11/28/73	60	15	6 9	
6752			120	inf	6 7	
6753			60	15	6 7	
6754	333	11/29/73	60	15	12	
6755			120	inf	7 12	

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-186-						
6756			60	15	6 7	
6757	333	11/29/73	60	15	1 5 10	
6758			120	inf	1 2 7 10	
6759			60	15	1 5 10	
6760	334	11/30/73	60	15	1 2 10	
6761			120	inf	1 2 4	
6762			60	15	1 2 10	
6763					11	
6764	334	11/30/73	60	15	6	
6765			120	inf	6 9	
6766			60	15	12	
6767	335	12/1/73	60	15	1 2 10	
6768			120	inf	1 2 3 4	
6769			60	15	1 2 10	
6770					11	
6771	335	12/1/73	60	15	1 12	
6772			120	inf	1 7 9 10	
6773			60	15	1 12	
6774	336	12/2/73	1/1000	15	6	Calibration frame.
6775			10	15	1 6	" "
6776			30	15	1 6	" "
6777			60	15	1 2 10	" "
6778			120	15	1 2 4 10	" "
6779			120	inf	1 2 3 4	
6780			60	15	12	
6781					9 12	
6782	336	12/2/73	120	inf	1 6 9	
6783			60	15	1 12	

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-186-						
6784	337	12/3/73	60	15	1 5 6	
6785			120	inf	1 2 3 4 5	
6786					11	
6787			60	15	1 6	
SL4-187-						
6788					11	
6789					11	
6790					11	
6791	337	12/3/73	60	15	11 12	
6792			120	inf	1 2 9	
6793			60	15	12	
6794	338	12/4/73	1/1000	15	6	Calibration frame.
6795			10	15	5 6	" "
6796			30	15	5 6	" "
6797			60	15	5 6	" "
6798			120	15	1 2 10	" "
6799			120	inf	1 12	
6800	338	12/4/73	60	15	6	
6801			120	inf	1 2 3 5 9	Frame was erroneously not scanned.
6802			60	15	5 6	
6803	339	12/5/73	60	15	5 6	
6804			120	inf	1 2 3 4 5	
6805			60	15	1 2 10 12	
6806	339	12/5/73	60	15	1 6	
6807			120	inf	1 2 3 4 5	
6808			60	15	5 6	

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-187-						
6809						Blank.
6810						Blank.
6811	340	12/6/73		inf	12	
6812	341	12/7/73	60	15	1 5 9 12	
6813			120	inf	1 5 6 7	
6814			60	15	12	
6815	341	12/7/73	60	15	1 5 6	
6816			120	inf	1 5 6 9	
6817			60	15	1 5 6	
6818	342	12/8/73	60	15	1 5 6	
6819			120	inf	1 5 6	
6820			60	15	1 5 6	
6821	344	12/10/73			11	
6822					11	
6823			120	inf	12	
6824						Blank.
6825	345	12/11/73	60	15	12	
6826			60	15	5 8 12	
6827			120	inf	5 7 8	
6828	346	12/12/73	60	15	5 7 8	
6829			120	inf	5 7 8	
6830			60	15	5 8	
6831	346	12/12/73	60	15	12	
6832			120	inf	1 2 3 12	
6833			60	15	12	
6834	347	12/13/73	60	15	8	
6835			120	inf	8	

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-187-						
6836			60	15	5 11	
6837	347	12/13/73	60	15	1 5 6	
6838			120	inf	1 2 3 4 5 9	
6839			60	15	1 2 3 10	
6840	347	12/13/73	60	15	8	
6841			120	inf	1 2 3 7 10	
6842			60	15	12	
6843	348	12/14/73	60	15	8	
6844			120	inf	8 9	
6845			60	15	8	
6846			60	15	8	Date of these frames
6847			120	inf	8 9	was not logged. Pro-
6848			60	15	8	bably 12/14 or 12/15.
6849	350	12/16/73	60	15	8 12	
6850			120	inf	8 9	
6851			60	15	8	
SL4-188-						
6852					11	
6853						Blank.
6854	350	12/16/73	60	15	8	
6855			120	inf	8	
6856			60	15	8	
6857	351	12/17/73	60	15	8	
6858			120	inf	8 9	On very edge of frame.
6859	351	12/17/73	60	15	8 9	
6860			120	inf	8 9	
6861			60	15	8	

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-188-						
6862	351	12/17/73	60	15	8 9	
6863			120	inf	8 9	
6864			60	15	8	
6865						Blank.
6866						Blank.
6867	352	12/18/73	60	15	7 8	Just off edge of frame; some tail.
6868			60	15	8	" "
6869			60	15	8	" "
6870	353	12/19/73	60	15	7 12	
6871				inf	7 8	
6872				15	8 12	
6873						Blank.
6874						Blank.
6875				inf	7 8 12	
6876	354	12/20/73	1/1000	15	8	Calibration frame.
6877			10	15	8	" "
6878			30	15	8	" "
6879			60	15	8	" "
6880			120	15	8	" "
6881			120	inf	8	
6882	355	12/21/73	60	15	8	
6883			120	inf	8	
6884			60	15	8 12	
6885	355	12/21/73	60	15	8	
6886			120	inf	7 8	
6887			60	15	8 12	
6888	356	12/22/73	60	15	6	

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-188-						
6889			60	inf	1 2 3 4 5	Comet in bright background near edge of frame.
6890			60	inf	1 2 3 4 5	" "
6891	356	12/22/73	60	15	12	
6892			60	15	12	
6893	356	12/22/73	60	15	1 2 7 12	
6894	357	12/23/73	60	15	11	
6895			60	15	5 8	
6896			60	15	12	
6897	357	12/23/73	60	15	12	
6898			60	15	8	
6899	358	12/24/73	60	15	8	
6900			60	15	12	
6901	358	12/24/73	60	15	11	
6902			60	15	12	
6903	359	12/25/73	60	15	12	
6904						Blank.
SL4-189-						
6905						Blank.
6906						Blank.
6907	08	1/8/74	60	15	1 2 3 5 9	Not enough stars for data reduction.
6908			120	inf	1 2 3 5 9	" "
6909			60	15	1 2 3 5 9	" "
6910	10	1/10/74	60	15	1 2 3 5 9	" "
6911			120	inf	1 2 3 4 5 9	
6912			60	15	1 2 3 5 9 10	" "

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-189-						
6913	10	1/10/74	60	15	11	
6914			120	inf	11	
6915			60	inf	6	
6916	11	1/11/74	120	inf	1 2 4 5	Comet on edge of frame; tail out of field of view.
6917			1/1000	15	8	Calibration frame.
6918			10	15	8	" "
6919			30	15	5 8	" "
6920			60	15	5 8	" "
6921			120	15	5 8	" "
6922	12	1/12/74	60	15	5 8	
6923			120	inf	5 8	
6924			60	15	5 8	
6925	13	1/13/74	60	15	5 8	
6926			120	inf	5 8	
6927			60	15	1 2 3 12	
6928	14	1/14/74	60	15	5 8	Comet on extreme edge of frame.
6929			120	inf	5 8 12	
6930			60	15	5 12	
6931	14	1/14/74	60	15	5 12	
6932					12	Apparently overexposed.
6933					12	" "
6934	14	1/14/74	60	15	12	
6935			120	inf	12	
6936			60	15	12	
6937						Blank.

TABLE 2. PHOTOGRAPH CHARACTERISTICS (Continued)

FRAME # *	DAY OF YEAR	DATE **	NOMINAL EXPOSURE TIME (sec)	FOCUS (ft)	FRAME CLASSIFICATION - (Refer to Code)	COMMENTS
SL4-189-						
6938						Not a comet photograph.
6939	30	1/30/74	180	inf	8	
6940			180	15	12	
6941						Blank.
6942	30	1/30/74	180	inf	7 12	
6943			180	15	11	
6944				15	1 7 10	Exposure time not logged.
6945				inf	1 6	" " " "
6946	33	2/2/74	120	inf	1 2 4	
6947			60	15	1 6 10	Calibration frame.
6948			30	15	1 6	" "
6949			10	15	1 6	" "
6950			1/1000	15	1 6	" "
6951	34	2/3/74	120	inf	7 12	
6952			120	15	7 12	
6953	35	2/4/74	120	inf	11 12	
6954			120	15	11 12	
6955	35	2/4/74	120	inf	7 11 12	
6956			120	15	7 11 12	
6957	36	2/5/74	120	inf	1 6 7	
6958			120	15	1 6	

TABLE 2. PHOTOGRAPH CHRACTERISTICS (Concluded)

EXPLANATION OF CODE

1. Comet position in field of view.
2. Comet coma image can be identified.
3. Part of tail image can be seen.
4. Frame used in analysis.
5. Spacecraft parts block portion of field of view.
6. No visible comet image.
7. Camera or spacecraft movement - irregular images.
8. Comet not in field of view - camera incorrectly pointed.
9. Smeared images due to momentum dump.
10. Frame not used in analysis - image density at or below background level or too much movement of image in frame.
11. Photograph cannot be identified.
12. Quality of photograph bad - no further consideration given to frame.

FOOTNOTES

* Frame numbers denoted by SL4-186-XXXX, SL4-187-XXXX, SL4-188-XXXX, and SL4-189-XXXX are contained on cassettes BH03, BH04, BH05, and BH06, respectively.

** Dates are tabulated at the beginning of each sequence; i.e., two identical dates given in the table denote two sequences on the same day nominally separated by 12 hours.

___ The frames numbers which are underlined refer to those frames containing data that were reduced and used to obtain the comet magnitude.

calibration sequences recorded the comet successfully. Typically, the Skylab attitude was being held inertially fixed during these exposures.

This distribution fell short of the goal of a sequence every half day but, nevertheless, provided some interesting observations. The successful observations after perihelion were especially scant. When attempted sequences failed, the apparent reason is given in Table 2. The table indicates with an underline which photographs were measured and analyzed. Most of these were focused frames. This choice followed from the postflight recognition that the comet did not become as bright as predicted during the preflight planning, and saturation of the cores of stellar images was not a significant problem. Use of the focused images gave a larger number of stars for reference and better signal-to-background ratios. When more than one photograph in an observation sequence had comet images, only the best frames were completely analyzed.

III. COMA MAGNITUDE

One result from the Comet Kohoutek photographs is a small sequence of visible light measurements of the stellar magnitude of the comet coma. The interesting topic that might be addressed from these measurements is the manner in which the coma magnitude increases as the comet approaches the Sun and decreases as the comet recedes. Conventionally, such data are reduced to a constant Earth-comet distance (1 AU) and plotted versus the log of comet heliocentric distance in astronomical units. When so displayed, the pre- and postperihelion curves may show a systematic displacement for equal heliocentric distances.

Table 3 gives the results of a final reduction of the successful S233 observations. Except for the observations on December 22, the data were processed using digital computer codes developed in connection with the S233 experiment but designed to have broader applicability to subsequent problems of a similar nature [5].

One column in Table 3 gives the number of reference stars selected for each frame to derive a calibration curve of stellar magnitude versus the log of the summed image exposure. Visual stellar magnitudes from the SAO Star Catalog [6] were used, and stars selected were limited to spectral classes F, G, and K. These choices correspond closest to the expected spectra of the comet and to the spectral response of the film-window-lens system used to record the photographs. The magnitude-versus-log-exposure curve then allowed a determination of the comet magnitude from the summed exposure of the comet image. Table 3 also gives the magnitude range of reference stars. In all but three instances, the comet magnitude was an interpolation from the reference curve. For frames 6889, 6890, and 6916, an extrapolation was necessary. Frame 6916 also had the lowest number of reference stars; therefore, the determined comet magnitude is somewhat less reliable for this case than for the other frames.

TABLE 3. RELATED DATA FOR ALL THE FRAMES FROM WHICH A COMET MAGNITUDE WAS OBTAINED

FRAME NUMBER	DATE M/D/YR	GMT OF PHOTOGRAPH HR:MIN	HELIOCENTRIC DISTANCE r(AU)	GEOCENTRIC DISTANCE Δ(AU)	# OF STARS USED FOR CALIBRATION	RANGE OF MAGNITUDES USED TO DETERMINE CALIBRATION	MEASURED MAGNITUDE	MAGNITUDE ADJUSTED TO Δ = 1 AU
Pre-Perihelion								
6739	11/26/73	04:40	0.9917	1.4730	26	2.8-7.1	6.2	5.4
6742	11/27/73	02:41	0.9709	1.4529	18	4.8-7.1	6.6	5.8
6761	11/30/73	03:15	0.9003	1.3887	42	3.2-7.6	5.6	4.9
6768	12/01/73	03:05	0.8773	1.3690	58	2.8-8.3	5.3	4.6
6778	12/02/73	02:21	0.8541	1.3498	23	2.8-7.0	5.9	5.2
6779	12/02/73	02:24	0.8541	1.3498	74	2.8-8.4	5.9	5.2
6785	12/03/73	03:16	0.8291	1.3299	57	3.3-8.4	5.6	4.9
6804	12/05/73	00:22	0.7828	1.2957	39	4.2-8.1	5.2	4.6
6807	12/05/73	12:48	0.7699	1.2867	34	3.3-8.9	5.7	5.2
6838	12/13/73	13:30	0.5574	1.1756	42	3.5-7.5	4.5	4.1
Near Perihelion								
6889	12/22/73	02:43	0.2985	1.1364	36	3.8-7.2	1.2	0.9
6890	12/22/73	02:44	0.2985	1.1364	39	3.8-7.2	1.1	0.8
Post-Perihelion								
6911	1/10/74	01:36	0.4934	.8344	20	3.0-6.8	3.9	4.3
6916	1/11/74	13:23	0.5365	.8208	17	3.8-7.0	2.8	3.3
6946	2/02/74	12:00	1.0768	1.0319	25	4.5-8.6	6.8	6.7

The observations on December 22 (frames 6889 and 6890) required special treatment. They were taken under difficult circumstances -- only 6 days before perihelion and 6 days before the comet's apparent least solar separation as seen from Earth. From Skylab, the comet rose only 3 min before the Sun. Under these circumstances, some scattered sunlight from the Earth's atmosphere on the horizon was illuminating Skylab, even though the comet was somewhat above the horizon. This illumination scattered off struts holding the Skylab solar instruments. Because these struts were in the photographic field not far from the comet, the scattered light resulted in an appreciable gradient within the background recorded around the comet. Also, the comet image was near the edge of the photographs. Under these peculiar circumstances, the computer codes used in the routine analyses were inadequate. Instead, the background was modeled in three distinct regions by a linear function of the row and column coordinates of the digitized data. This modeled background was subtracted from the comet data.

In those cases, such as December 22, when an appreciable tail was photographed, the coma in the tailward direction was treated as a region of extent corresponding to that occupied by the opposite side of the coma. That is, for the purpose of coma magnitude determination, the coma was treated as a symmetric region.

The measured magnitudes from Table 3 can be compared with models of coma magnitude-versus-heliocentric distance derived by other authors. For comparison purposes, two typical models are used in Table 4.

The first model is due to Deutschmann [7]. As his preferred model, for a heliocentric distance, r, he gives:

Preperihelion

$$M = 5.95 \sqrt{r} - 0.92$$

Postperihelion

$$M = 6.86 \sqrt{r} - 0.50.$$

This magnitude is tabulated in Table 4. For comparison with the observed magnitudes from Table 3, an aperture correction as applied by Deutschmann must be made. He adopted -0.066 mag cm^{-1} for refractors, which results in a -0.30 magnitude correction for the lens of 4.6-cm aperture used in the observations here. In Table 4, this correction is applied to the Table 3 values, and differences between the observations and model are shown.

Deutschmann also applies an observer correction to the data from each observer. To examine this possibility for the data in Table 4, the observations on frames 6889 and 6890 were excluded as physically not within

TABLE 4. COMPARISON OF THE MAGNITUDE OBTAINED FROM SKYLAB WITH THE BEST-FIT DATA OF DEUTSCHMANN AND KLEINE AND KOHOUTEK

FRAME NUMBER	MAGNITUDE ADJUSTED TO $\Delta = 1$ AU	MAGNITUDE WITH -0.30 APERTURE CORRECTION	MAGNITUDE CALCULATED FROM DEUTSCHMANN FIT	DIFFERENCE	MAGNITUDE WITH -0.17 APERTURE CORRECTION	MAGNITUDE FROM KLEINE & KOHOUTEK FIT	DIFFERENCE
Pre-Perihelion							
6739	5.4	5.1	5.0	0.1	5.2	5.1	0.1
6742	5.8	5.5	4.9	0.6	5.6	5.0	0.6
6761	4.9	4.6	4.7	-0.1	4.7	4.8	-0.1
6768	4.6	4.3	4.6	-0.3	4.4	4.8	-0.4
6778	5.2	4.9	4.6	0.3	5.1	4.7	0.4
6779	5.2	4.9	4.6	0.3	5.1	4.7	0.4
6785	4.9	4.6	4.5	0.1	4.8	4.6	0.2
6804	4.6	4.3	4.3	0.0	4.4	4.4	0.0
6807	5.2	4.9	4.3	0.6	5.0	4.4	0.6
6838	4.1	3.8	3.5	0.3	4.0	3.5	0.5
Near Perihelion							
6889	0.9	0.6	2.3	-1.7	0.8	1.8	-1.0
6890	0.8	0.5	2.3	-1.8	0.6	1.8	-1.2
Post-Perihelion							
6911	4.3	4.0	4.3	-0.3	4.2	3.9	0.3
6916	3.3	3.0	4.5	-1.5	3.1	4.2	-1.1
6946	6.7	6.4	6.6	-0.2	6.6	6.9	-0.3

the model scope (see later discussion). When an observer correction is derived with the remaining data in Table 4, using the model values as a reference, the observer correction is approximately $\pm$ 0.1 magnitude, with the sign depending on whether the questionable value for frame 6916 is included. Therefore, no observer correction is applied. The small size of this potential correction can be viewed as a favorable measure of the analysis methods applied.

Figure 1 illustrates the Deutschmann model and the observations from Table 4. The questionable value from frame 6916 is not shown.

A second model for comparison is one due to Kleine and Kohoutek [8]. They give:

Preperihelion

$$M = 5.11 + 6.38 \log r$$

Postperihelion

$$M = 6.63 + 8.92 \log r$$

For this model, an aperture correction, -0.037 mag cm^{-1}, is specified by the authors, which results in a -0.17 correction for the 4.6-cm aperture. The values from this model and observed values corrected for aperture also are given in Table 4. These are depicted in Figure 2.

The coma magnitudes for frames 6889 and 6890 are probably significantly brighter than calculated from either model. Other authors have noted that observations near perihelion were brighter than indicated by the various models; for example, Jacchia [9].

IV. COMET TAIL ON DECEMBER 22

Two photographs made on December 22 recorded a tail some 5 degrees long. The comet image from frame 6889 is reproduced in Figure 3. Near its end, the image of the tail is lost in the bright background near a dimly illuminated spacecraft spar. Under more favorable circumstances, a longer tail might have been detected.

Figure 4 is a digital representation of the exposure of the comet image above background from frame 6889, after reduction using the appropriate D-versus-log-E curve and camera vignetting curves as discussed earlier. The contours in Figure 4 are drawn to show the extent of the tail and some of the inner portion of the comet. Also shown at the same contour level as that of the tail are contours of a known set of stars in the field.

The numbers shown in the figure are 100 times the actual exposure values for each pixel after correcting for vignetting and subtracting the

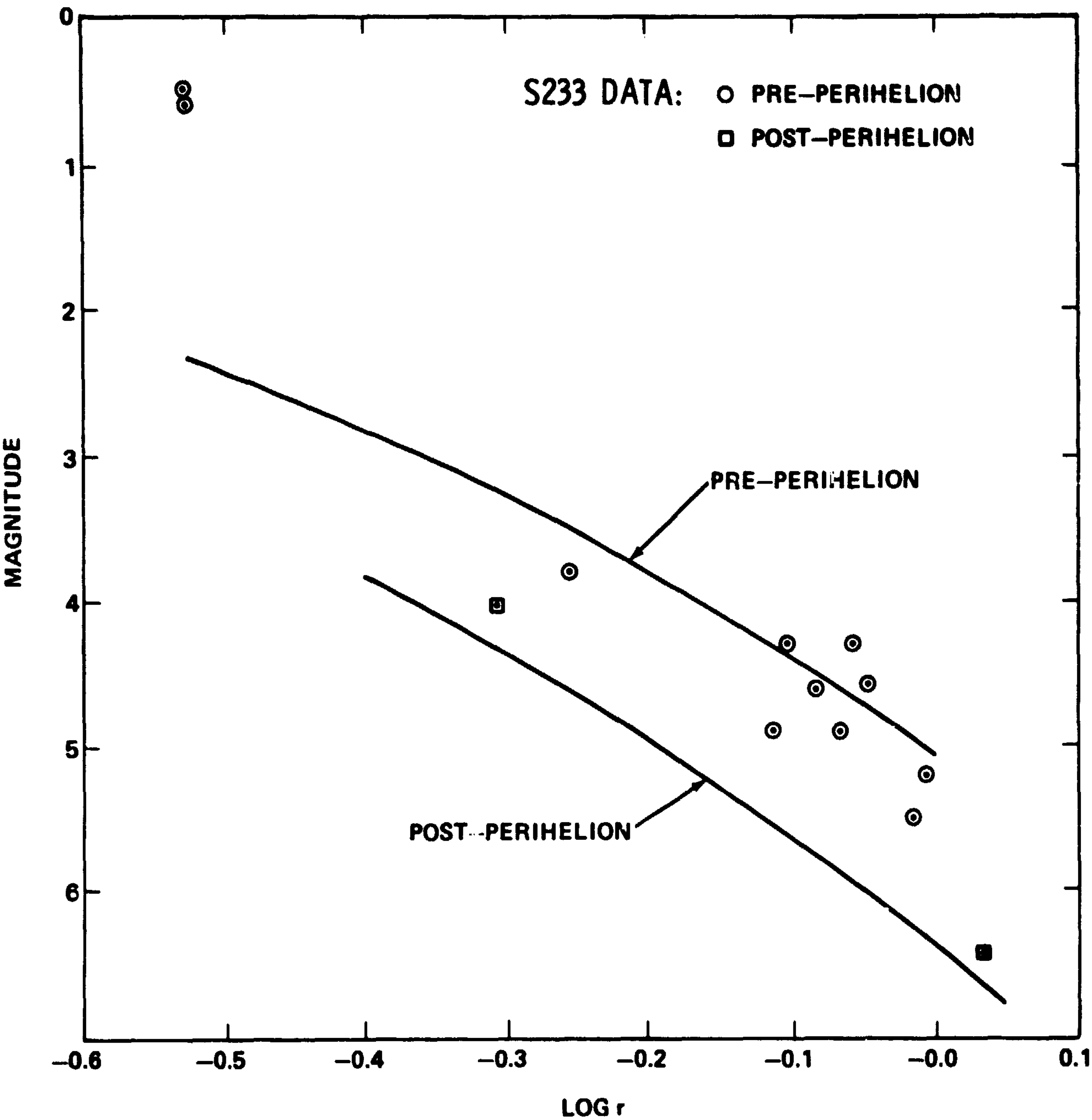

Figure 1. Comparison of S233 results with the model developed by Deutschmann for ground-based observation data.

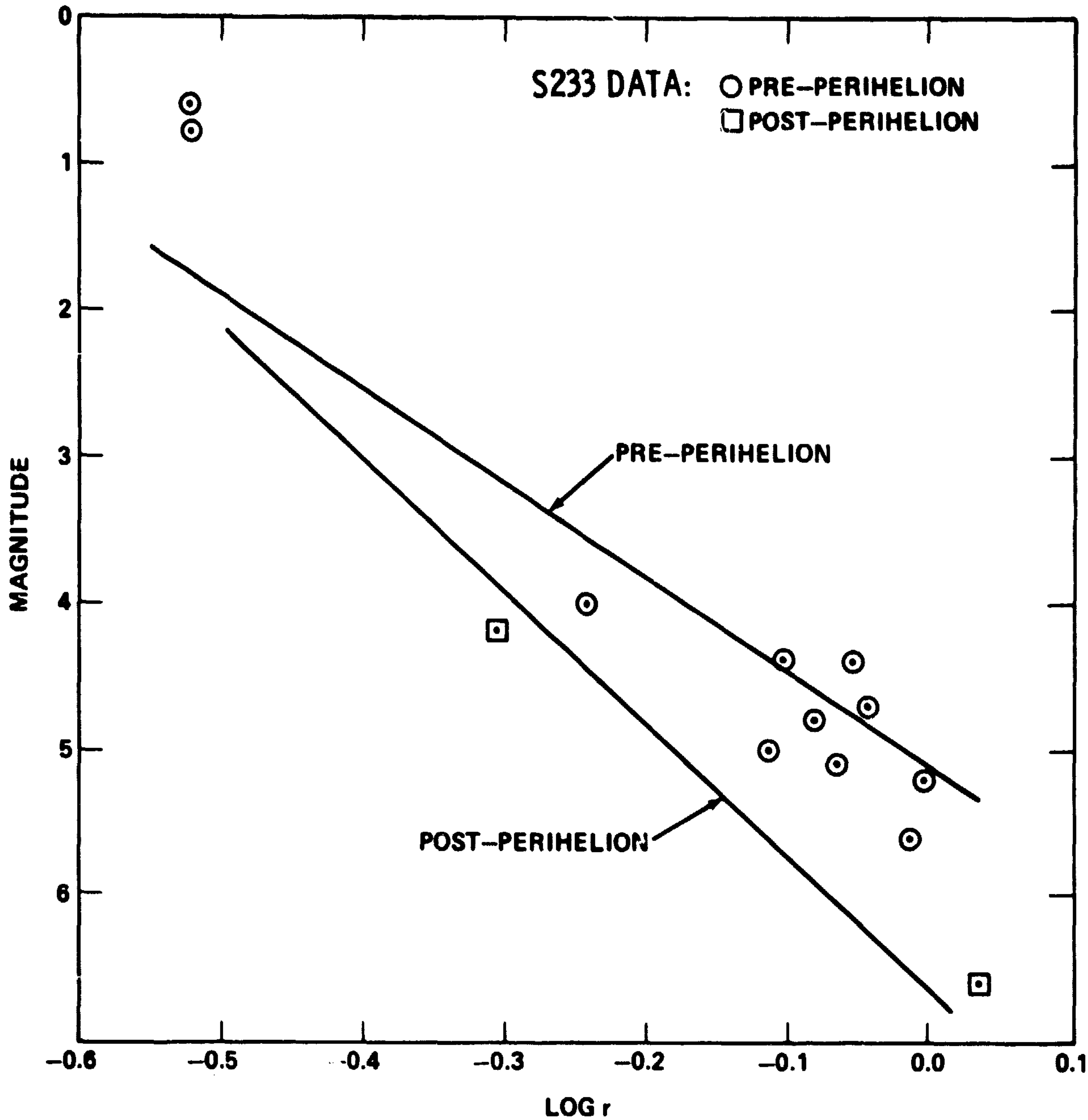

Figure 2. Comparison of S233 results with the model of Kleine and Kohoutek.

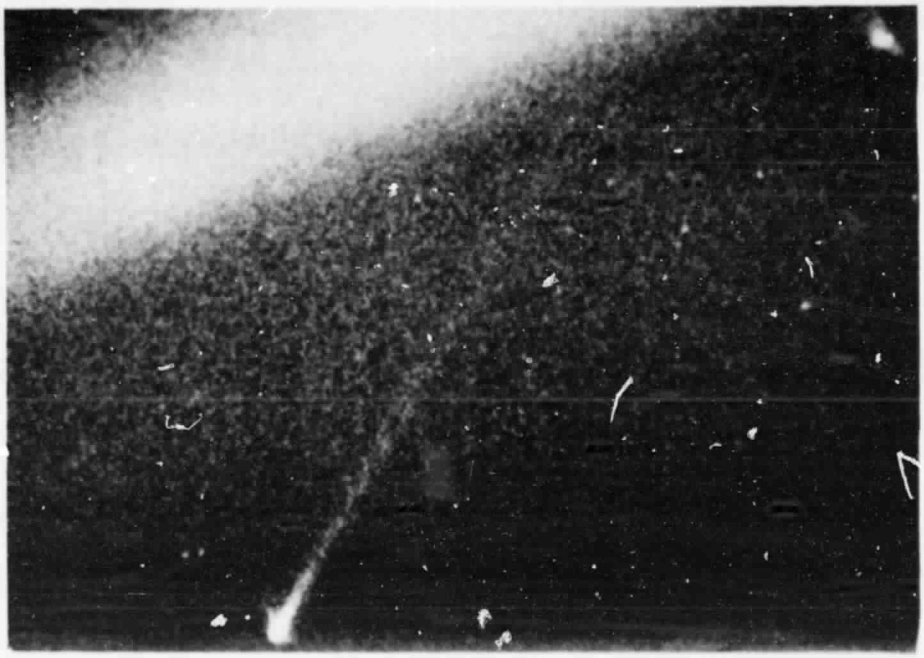

Figure 3. Comet Kohoutek image from frame 6889.

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101 96 76 85 80 74 67 32 46 49 49 40 27 34 37 46 43 51 50 39 22 29 25 35 11 18 24 11 21 4 26 26 20 20 16 3 16 9 15 9 5 3 11
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40 99 96 46 53 49 61 61 34 27 47 40 30 25 25 18 4 3 17 24 24 23 23 13 2 9 16 2 8 8 4 1 1 11 4 7
65 64 64 90 53 72 46 35 45 48 40 51 50 33 12 4 22 21 38 41 34 14 26 4 3 16 26 26 2 5 5 15 25 12 5 21 18 1 1 1 1 1 1
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24 31 24 23 8 25 14 10 13 13 9 9 8 8 12 8 1 8 4 5 6 6 9 5 8 15 18 5 14
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               5 7 10 5 8         3 8 11 1        1 1 2                       3 5      3      4 4     2 4 5 5      5
13              13 2               6 3                                 5 8 5 6           4           4          3    3
22 13 2 13 2        6 3 6 14 14          7 9      4 2 7 2 2           8           6 14 1     9 10 5                     6 6
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  6                                 4                             1     1                                 6 6 22 9 14 20
                    10 10                2 5      11 11 9 3      6 4 1 4        16     3      3 8 1 11 6 17 14 7
23 18              2 7         8 13     5         3 3 1    12 4      2 2                8                 4 7 12 12 2
7 21 18     2     7 8                3 3        6 5          7 4               5 13 5 3 3           4 9 26 7 5 7 8 8
16 16 10 5 5 5 5 5 5             3 14            7 4 15 2                      3          6     1 7 2 7     2 8 8 13
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            9 2 7       7 2             16 11 3          2 9 17 12 5              13 12        2             6 9 3 7 5 1 6 8 6
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15 2 4 2                           5 8                  4 9 3 3 3                 2       6 6 9       1 3 1 1
       10 13 5                                  2             12 15 7        1 4 4 4              7 1 5 3 7 16 2        4 4 5 5
10 7        5 5 5 4 6 2 4 8          4 7 3                                2 16 2 13 16 5 3 3 7 4 6              4         3 3 1
     1              2                  5 5 5 5                   10 16        2 4             1 5 1                 4 5                      4
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26 9   8 11 28 19 4 14 7 10   3 6 13 25 2   11 15 4 7   22 25 17   5   2 9 5 2   4 12 12
39 43 13 3   2 16 20 5 11   18 18 10   6 6 6   5   12 5   11 1 4 11 4   1   13 25 6 9 13   5   2 12 2   5 8
8 14   7   3 12 5 15 19   1 4 14 14 10   3   13 20 8 5 2 2   11 4 15 7   6 24   3 13   13 3   3 5
5 8 1   10 13   19 1 1 16 7 10 17 17 6   6 16 5 5 2   15   11 26 14 10 4 1   6 13 13
9   2 2   1   1 26 29 3   12   2   8 15 18 26 1   17 13 3 13 20 28 8 2   5 5 23 22   2 7   6
25 16 20 19 5 32 35 4 4 7 10   6 6   6 2   8 8 10 1 16 4 16 5 17   6   3 6   2   5 8 19   7
4 16   12   15 23 11 5 1   4   5 6   8 15   2 7 4 1 7   3 9 13 6 3 8 12 3 16   5 15   2   7 18 7
1 7 4 21 16 9 3 9 27 8 2   1   13 10 6   3   2 2 11 15 10 4 4 7 10 10 21 13   9 5 5   3 3   6   3   15
5   11 26 13 16 20 6 3 2 12 5 5 5 22 4 7 1   17 20   6   5 2   7   1 13 9   1   1 6   6 8
9 12 5   8 21 13 25 29 3 24 15 3   8 11 8 11 1   4 7   6   16   2 11   2   4
7   13 12 6 27 11 11 5   13 4   4 24   3 6 9 2   5 5 6 6 10 7   4   1 4 24 20 3   6   3 11
8 2 21 8 4 10   7   6 6 12 14 17 5 11 16 4   4 4 3 6 15 3 3 3 3   2   2 2 4 4 7 4 10 12 1 1   1 1   4
3   6 9 12 25 8 11 7 4 4 7   6 12   6 12   24 7   4 15 3   5 14   3 6   3 14 21   8 17 20 10 20 20 10
14 4 1 4 13 9 6 15 2 2   8   4 19 10   11 14 5   10 7 7   4   6   3 14 18
15 15 5   8 7 10 7   9 12 9   12 8   5   1 1 7 6 12 12 3 3   5 5 2   5 5 2 2 4   2 4 7 7 10 1
10 6 3 2   2 11 8 11   10 16 6 6 9 12 5 5 20 24 8 5   7 4 4   1   6   6   3   6   5 13 11
8 11   3 3 3 12   1 1 7 10 1 7 3   12 6 5 2   8   5 2   7   1 4   12 7 6 1 12   6
3 9 15   21 14 7 17   3 12 6   5   4 13   1 1   3   9 3 9 5   5 5 2 2
17 20 20 10 6 16 22 5 15 14 17 14 7   1 7 7 25 12 12 6 12 12 8 5 11 20   11 10 4 13 10 10 1   7   4   3 12 9   3   6
36 18   6   6 2   15 11   14 7   7 16 4   5   6   6 12 8 8   20 22   13 10 10 4 2   1 10   4
3 13   18 11 11 8 4 10 17 4 3   12 2   2 2 4 13 13 10 10 19 10 12 12 24 16   3 9 6   11   11   5
4 7 13 10 13   12 2   5 5 14 1   1   13 3 6   3   8 17 11   6 2   4 1   7   5 4 4 4 15 12
5 2 21 21 14 7 20 17   3   3 18 5 2   8 4 7   4   6 15   12 15 9   5   13 7   13 2
10 23 23 12 12 18 5 1 1 1 20 1 4 10 13 6 16 6 6 6 5 11 2 2 17   2   7 13 13 1 1   1 6 5 3 3 15 15 9 12 11   8 6
7 7 4 7 6   2   5 14 17   1   3 3 6   2 5   5   11 5   4   10 4 1 7 1
5   2   11 4 1   3 15 12 5 2 2 5   4   4   10 15 10 4 15 9 15 18 15 16   3   6   11 17 14   2 16 5
9 25 5 5   21 17   14 17 29 13 10 13 3 3 12 12 5 18 14 2 6 20 32 20 5 7 13 13 1 1 4 1 1 18 21 7 1 1   3 3
8 4 1 4 7 17 6 19 19   5   5 14 6 1 4   10 4 1 1   5   15 12 12 18   2 11 20 8 2   2 2   8 2   2 2
2   2 2   14 7   3 3 3 6 3 5 21 21 5   7 4 1 16 16 4 10   3 6 1   6 9 3   6   3
10   6   15 28 18 8 11 17 7 10 7 4   3   6 3 2   5 2 5 8 35 16   10 16 7 4   4 9
22 32 8 1 10   4 13   9   8 5 2   1 4 10 10 7   5 21 27 30 6 6 52 25 26 8 5   2 13
20 23 6   11   1 1 1 9 5 12 5   16   6   17 55 67 25 4 16 45 16 7   7 7 4   1 1   12 18 18 9 1 3
21 7 1 7 7   12 11   2 4 1 1 4   5 27 30 20 26 6 17 6 14 8 8 5 8 2   5   2 2   2
15 15 11   7 13   7 16 1 13 10 10 13 15 28 27 18   5 15 5 3   8 8 3 6 6 14
4   12 15 2   2 8   1 7 1   6   5 5   5 20 10 10 2   1 9 1   1
1 7 7   6   14 7 13 4   1 1 4 6 6   3 11   5 11   5   2
7 1   9   6   6 2 2   13 13 7   1 4 4   1   1
9   2 2 14 8 14 1 1   12 12 3   7
5   4 4 7 7 4 3   5 9 15 6 11   5 2 2 2   7 7 12 12 4   6   3   3 11 6
6 6 6   5 14 1 4 7 4 4   14 6 6   7 7 15 1
7   7 6   5 11 11   1 4 10 16 7 4 1 4 5 15   3 3 9 3   3   3 3   3   3 5   3
5   5   7   6 5   5 2 2 5   8 6 5   4   9 6 1   4
10 10 23 22 9 15   3   5 5 5   5   5   2   7 7
1 4 17 14 4   3   5 2   5   7 4 7 7   4 3 6   6 12 12 6 3   3 14
3   5   1   1 10 19 7   6 17   10 6   7 12
6 3   2   4 13 10 3 3 3 5 3   12 14   3   6   5
5 11 8   13 7   6 3 12 15   2   1 4 10 4   7 7 10   4 4   1 6 4   1
6   9   1 7 14   3   3   2 6 5 12 3   11 2 5 8 5 10   2 10 24 10
3 16   5   11   4 7 13 1 13 28 22   6 12 6   3   9   11 11
11 31   9 6 6   5 15 12 14 5   11 2   1 12 1 10 10   12
13 20 19 9   5   8   17 17 10   4   2 5   3   5 3   5   5   8 8   8   5
8 21 14   7 1   6   19 15 6   15 8   2   4 7   4   16 16 7 4   4 3   6 9 1 3   15 15 6
9 9 16   2 11 14 7   1 1   3 6 12   20 17 8   19 5 7   7 3 2   7 5 16
4   3 3   3   8 2 5 6 11   2   1 10 7 10 7   1   6   1   3 6 3   17 23 8   3   1   1
2 11   7 4 1 1   1 3   3   3 11 27 2 11 17 2 2 4 15 4   2   2   4 4 2 10   4 7 2 4 16 10 10 7
12 9 6 17 24 13 10 7 7 7 1 1   5   10 8   2   1 1 4   3 20 20   5 2 5   2
7   3 3 21 3   2 2   1 18 1   3   5 3 2   8 2   5 2 7 15
5 14 4 14   7   1   3   11 5   2   11   5 2 2 6
8   4   9   5   2
5   5 2   3   7 4 7
```

FOLDOUT FRAME 4

ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME 5

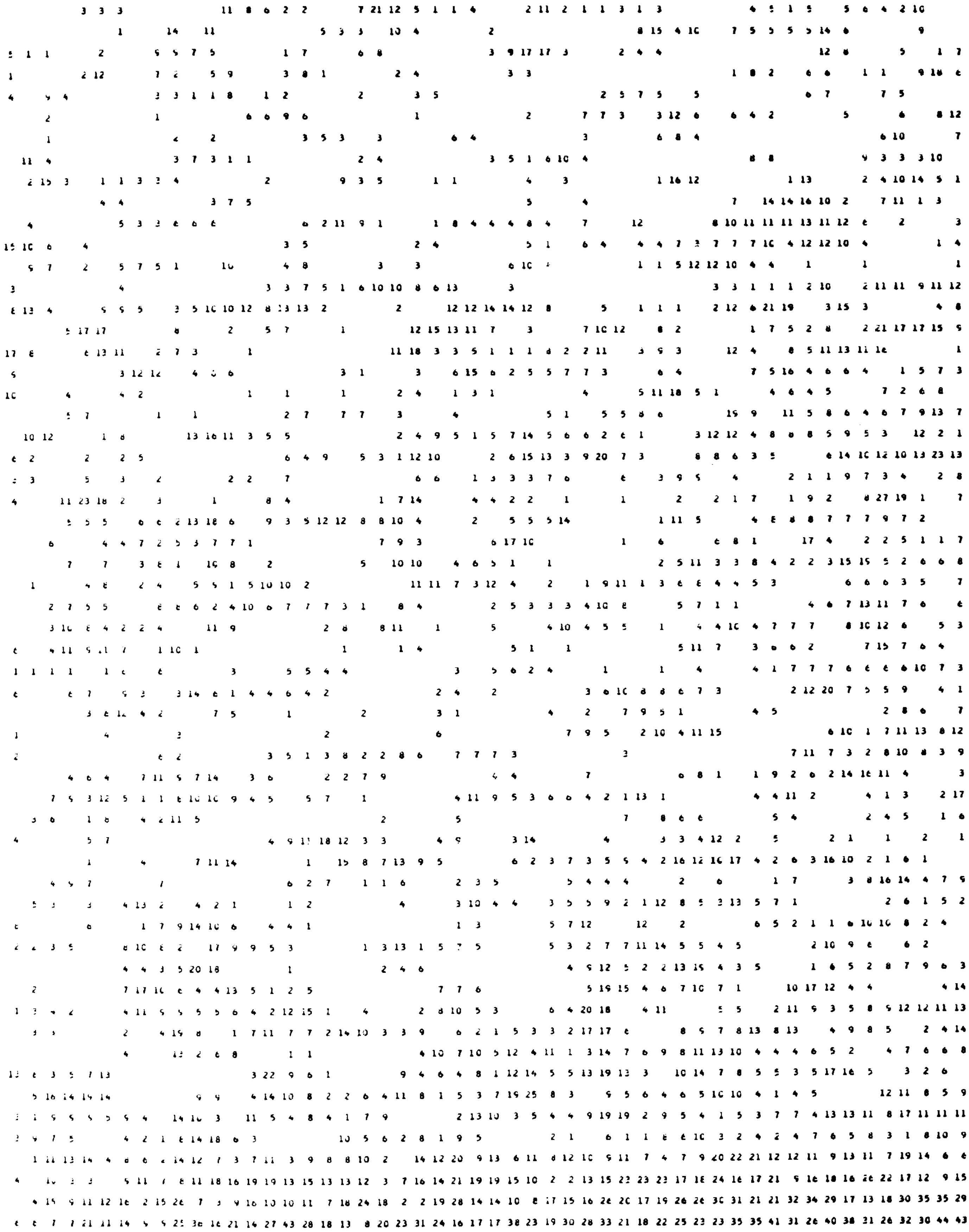

Figure 4. Digital representation from frame 6889 of the exposure values in the comet image after correcting for background and vignetting effects. The values shown are 100 times the actual exposure values.

background. To convert to radiance in 10th mag stars/degree^2, one should multiply each number by 1.53×10^2. This value includes the factor of 100 mentioned previously. (Each pixel covers 6.78×10^{-4} degree^2.)

V. CALIBRATION OF MAGNITUDE

The procedure for calculating the comet magnitude from each frame takes place in four steps. In step 1, the conversion curve from density to exposure (i.e., the density-to-log-exposure curve) is determined. In step 2, the background exposure around each reference star to be used in the calibration curve and around the comet is determined. Step 3 consists of finding the signal (i.e., the sum of the background-corrected exposure values) for each reference star image. Step 4 is the calibration of the full frame and the determination of the comet magnitude. This consists of fitting a straight line to the reference stars and then calculating the comet magnitude using this line.

All the densities were measured with the Optronics Spec Scan 3000 microdensitometer at the Johnson Space Center and were recorded in digital form on magnetic tape. One frame, 6946, also was measured subsequently on the Perkin-Elmer Micro 10 microdensitometer at the Marshall Space Flight Center. Data from the Marshall scan for this frame are quoted in this report, although the difference in the comet magnitude calculated from the Johnson and Marshall data sets is small. In all cases, a 25-μm square aperture was used to digitize the density readings, and each reading was separated from its neighbors by 25 μm in both the X and Y directions. All subsequent manipulation of these data uses copies, also on magnetic tape, of the appropriate frames.

The density to exposure conversion was made using a look-up table. Each density value was converted to an 8-bit gray scale value. This was a convenience for working with the IBM 360 and other machines with which the data reduction was done. A calibrated standard 21-step Kodak step-wedge image placed or each roll of the film postflight provided the D-log-E curve from which the look-up table was generated. These images were placed on the film using an exposure time of 60 sec.

Since the background varies over the area of a 35-mm frame, a value for the background exposure was found for the area around each reference star image and the comet image. This area, A_B, was normally a 1500-μm square area centered on the image (star or comet). The background was defined to be the average exposure value of all the exposures in the area. All the exposure values used in the average were first corrected for vignetting. Density values associated with stars or the comet were excluded from the average by limiting the density values to a band around the mode of the densities in the area; i.e.,

$$E_B = \frac{1}{N} \sum_{A_B} \frac{E(D_{ij})}{V_{ij}}$$

where V_{ij} = vignetting for i,j point, $D_{min} \leq D_{ij} \leq D_{max}$, and N is the actual number of data points used in the average. Of the 3600 possible data points in A_B, generally more than 75 percent were used to calculate a background value. D_{min} and D_{max} were subjectively determined from a density histogram, such as shown in Figure 5, constructed for each area A_B. The histogram shown in Figure 5 covers densities ranging from 30 to 64. For this area, D_{min} and D_{max} were chosen to be 36 and 42, respectively.

The total exposure value E_T for a given image on a frame was found by summing all the exposure values, corrected for background and vignetting, in the image. A rectangular area A_M around each image is defined as the image area. These areas are generally, but not always, centered in the corresponding square area A_B used for determining the background. They also varied in size depending mostly on the magnitude of the object but also somewhat on its position in the frame. A small area ($A_M << A_B$) is used for the sum in order to reduce the residual error resulting from the small difference between the true and calculated background and to exclude signal from other stars and sources. E_T is defined as

$$E_T(A_{M\ell}) = \sum_{j=1}^{\Gamma} \frac{E_{ij}}{V_{ij}} - \bar{E}_B(A_B)$$

where Γ = the total number of points in A_M,
E = the exposure of the point at coordinate point i,j,
V = the vignetting value at the point i,j,
i,j = the X and Y coordinates of the point,

and ℓ is a counter for the number of star images. In determining the signal from the comet, only values from the coma were used. The tail was excluded from A_{MC}, the comet coma area, by defining the coma as symmetric around a line perpendicular to the head-tail direction. The boundaries of A_{MC} in the tail direction were chosen to be the same distance from the coma center as the coma edge opposite the tail.

A calibration curve was defined for each frame using the E_T and magnitude of the reference stars in that frame. The reference stars were identified using the SAO catalogs. The visual magnitudes from the SAO catalog were used in determining the calibration curve. Stars selected for reference stars were limited to F, G, and K spectral classes, as noted in Section III.

The calibration curve for the frame is defined as the least-square fit of a straight line to all the reference stars using the equation

HISTOGRAM OF NEIGHBORHOOD FROM INPUT TAPE LABELED FRAME 6946 FROM SSL U–D FLT FLM 3/13/81
AND DESCRIBED AS KOH FRAME 6946 SSL SCAN FLT FILM
THE LOCAL NEIGHBORHOOD BEGINS WITH RECORD 363 AND ENDS WITH RECORD 422
IT BEGINS WITH ELEMENT 983 AND ENDS WITH ELEMENT 1042

NUMBER	COUNT	0 = MIN MAX = 545
30	1	/
31	1	/
32	9	/
33	21	/
34	69	/
35	154	/
36	303	/
37	449	/
38	545	/
39	529	/
40	507	/
41	387	/
42	238	/
43	161	/
44	89	/
45	35	/
46	27	/
47	13	/
48	6	/
49	8	/
50	4	/
51	1	/
52	1	/
53	5	/
54	3	/
55	1	/
56	4	/
57	2	/
58	4	/
59	3	/
60	0	/
61	1	/
62	1	/
63	2	/
64	1	/

VALUES OUT OF THE 30 TO 64 RANGE. 15

Figure 5. Density histogram for frame 6946 (Marshall scan).

$$\log E_T(A_{M\ell}) = am_\ell + b$$

where m_ℓ is the visual magnitude from the SAO catalog and a,b are constants determined from the fit.

Figures 6 and 7 are examples of the data and calibration curves. The comet magnitude is then found by inverting the preceding equation,

$$m_c = \frac{\log E_T(A_{Mc})}{a} - \frac{b}{a} .$$

The values found from this equation are given in Table 3 as the "measured magnitude" of the comet. Crosses in Figures 6 and 7 mark the comet magnitude on the calibration curve as determined from E_T for the comet for frames 6779 and 6911.

A measure of the error in this method can be given by the value of the root mean square (RMS) of the standard deviations of the reference star magnitudes from the several calibration curves. That is, the RMS represents standard deviations of the individual differences between the magnitude of a star as determined by the calibration curve for an individual frame and its value as given in the SAO catalog. The RMS standard deviation α_{all} for the frames used is

$$\alpha_{all} = 0.2.$$

Thus, on the average, any star's magnitude can be calculated to within 0.2 using this method.

VI. VIGNETTING

Direct measurement of the vignetting function of the specific lens used for these photographs was not possible. The lens was left on board the Skylab workshop, and sufficient time was not available for such measurement between the inception of this experiment and launch. Fortunately, measurements of the vignetting function for several similar lenses had been made for investigations on Apollo flights, in particular the Low Brightness Astronomical Photography (S211) investigation for which R. D. Mercer was the Principal Investigator. These data and how they are obtained are described elsewhere [10, 11]. From the data, Mercer concluded that there was little difference in vignetting patterns between the same lens type. We agreed with this conclusion and, thus, decided to base our vignetting correction on a single data set. We chose the 180-sec exposure frame taken through the Apollo 17 lens [10, 11] and a blue filter in order to obtain coverage over as much area of the 35-mm frame as possible. Figure 8, taken from Alvord [10], shows contours of the intensity recorded on that frame. The contours indicate the vignetting pattern used for the data reduction

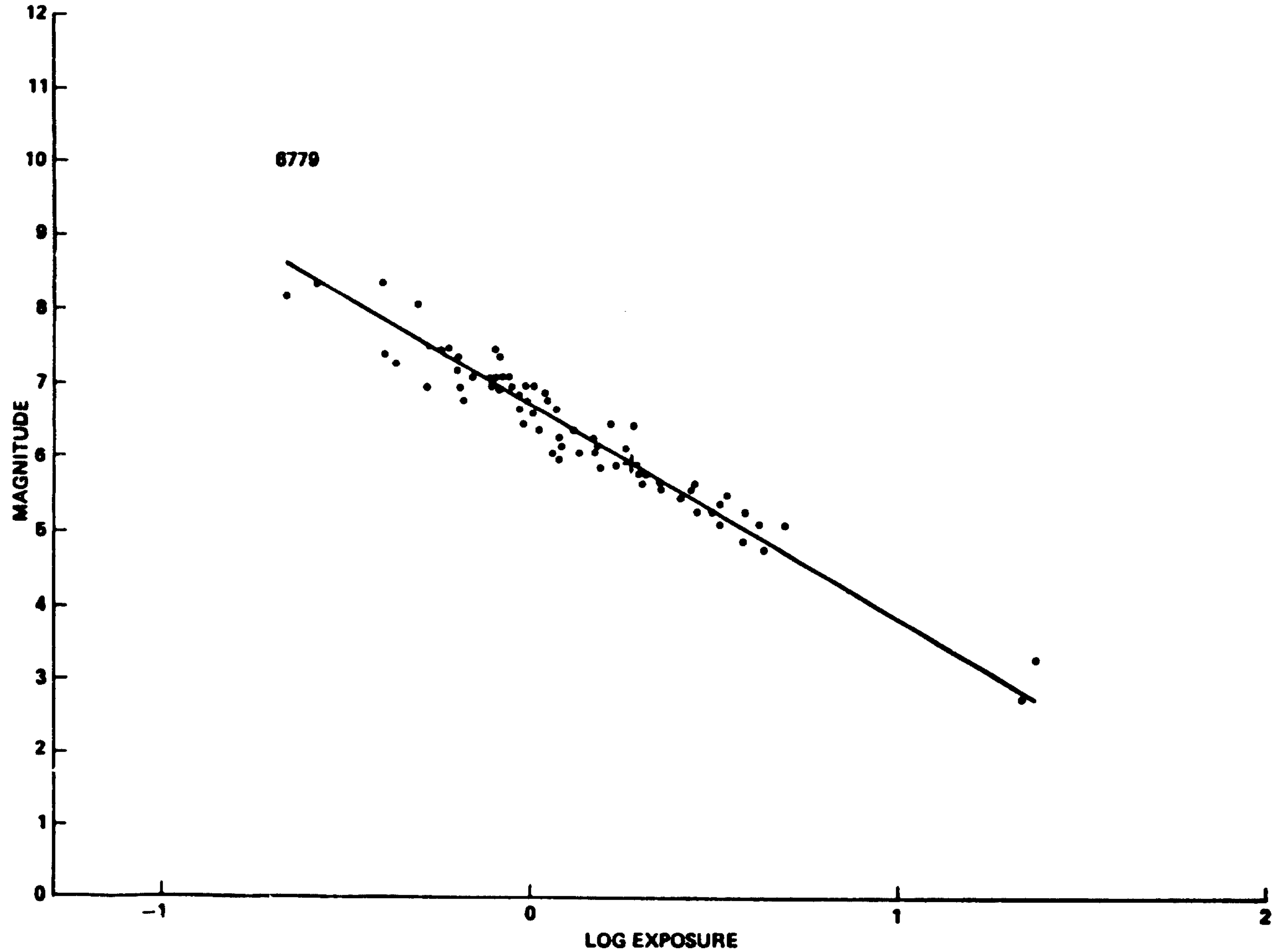

Figure 6. Reference stars and best-fit calibration curve derived from them for frame 6779. The comet position is denoted by the cross.

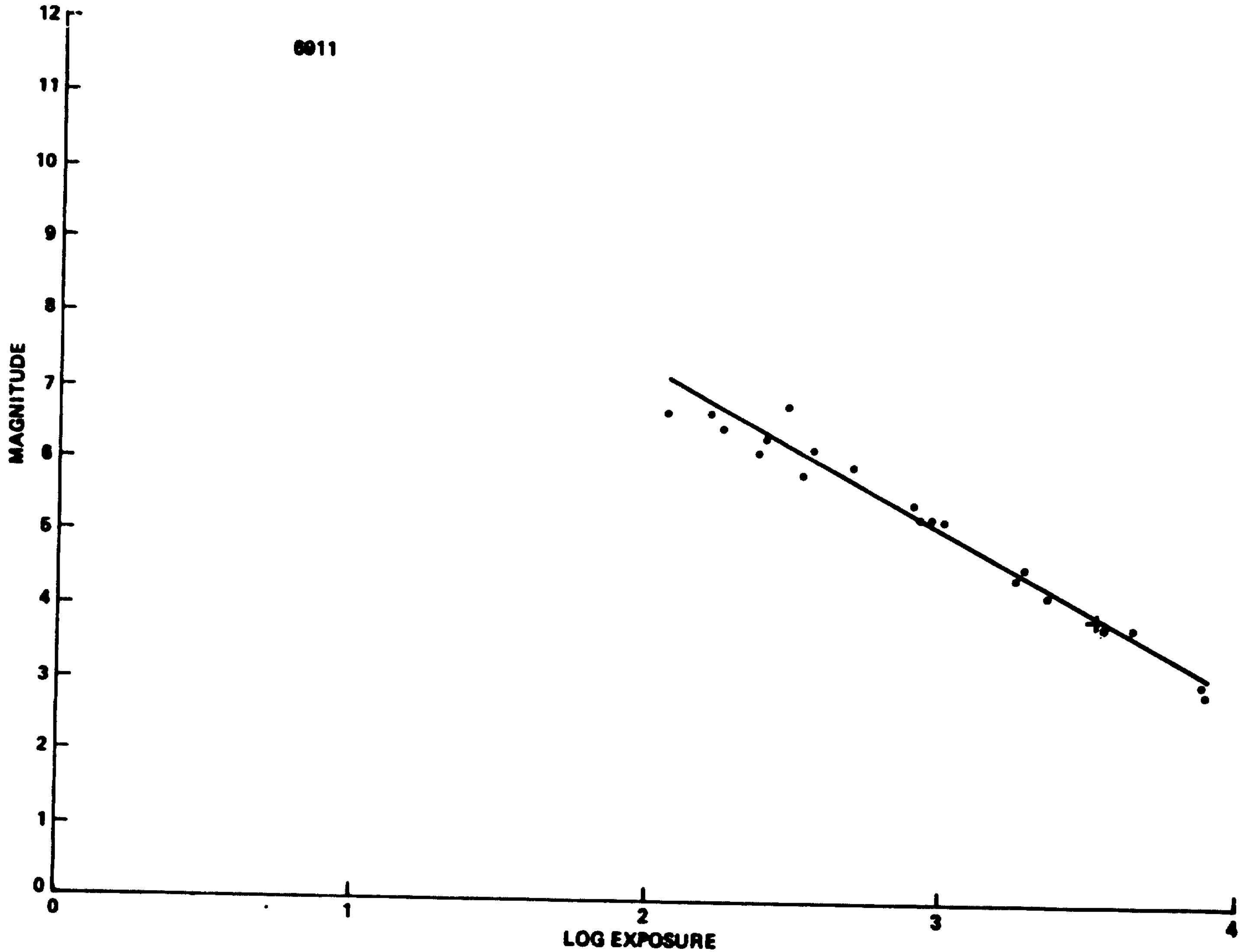

Figure 7. Reference stars and the calibration curve derived from them for frame 6911. The comet position on the curve is denoted by the cross.

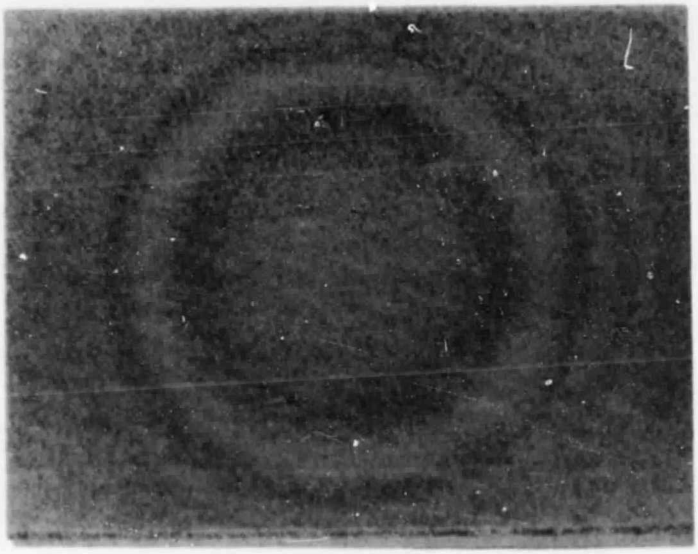

Figure 8. Contours of the intensity pattern caused by vignetting through a Nikon lens similar to the one used in this experiment [10].

here. It should be noted that the blue filter had no effect on the vignetting pattern of the lens.

To simplify the procedure for vignetting correction and to reduce the computer core storage requirements, smoothed exposure data from the frame referenced previously were fit with a curve of the form

$$V = \alpha + \beta R + \gamma R^2.$$

To model the vignetting pattern, R during the fitting process was the distance from the pattern center to the point in question. To compensate for a difference between the center of the vignetting pattern and the frame center, the X and Y offsets were two other parameters (five in all) which the computer program varied to find the best fit to the data. In application, however, R was used as the distance from frame center to the point in question because there was no way of knowing if an offset existed for the actual lens or how far or in which direction to offset the pattern.

For the data of Figure 8, the constants are:

$$\alpha = 1.9198,$$
$$\beta = -0.6861,$$
$$\gamma = -1.0032.$$

Since there are slight differences in the vignetting pattern between lenses, one might expect a systematic error between the reference star magnitudes and those calculated from the fit curve. Using scatter diagrams of $(M_{measured} - M_{SAO})$ versus R, no consistent systematic effect was found. Therefore, errors resulting from not using the exact vignetting pattern are small.

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APPROVAL

KOHOUTEK PHOTOMETRIC PHOTOGRAPHY EXPERIMENT (S233)
FINAL REPORT

By C. A. Lundquist and P. D. Craven

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

for William C Snoddy
J. E. KINGSBURY
Acting Director, Space Sciences Laboratory

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